Quantitative Mapping of Cerebral Blood Flow Change using Phase Information of SWI

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Introduction

Phase image of MRI contains information about local difference of magnetic susceptibility, originated from blood product, iron, etc. [1]. One of the recent utilities of phase image is susceptibility weighted imaging (SWI), which emphasizes susceptibility differences by using the phase shift of the spin derived from the paramagnetic substances mentioned above. By using the bulk susceptibility differences included in SWI, manual calculation of the blood flow changes and oxygen saturation in veins has been reported [2,3]. For an application of this theory, automated calculation of cerebral blood flow (CBF) changes can be achieved as a whole brain CBF mapping.

The purposes of this study were (1) to develop the automated method to obtain a map of CBF change, (2) to assess the reliability and stability of the automated method in measuring rest CBF, compared to the manual method reported previously [3], and (3) to evaluate the accuracy of this method in measuring CBF changes induced by the respiratory stress, compared to arterial spin labeling (ASL).

Materials and Methods

A 1.5T MR imager (Avanto, Siemens, Erlargen) was used to obtain phase images of SWI, with a fully velocity-compensated, three-dimensional fast low-angle shot (3D-FLASH, TR = 49 ms, TE = 40 ms, flip angle = 20°, and bandwidth = 80 Hz/pixel). The phase images were reconstructed and imported to our original program, Perfusion Mismatch Analyzer (PMA), to make CBF change (Δf) map. First, a high pass filter was applied to the phase image (Fig. 1A). Then, the veins were extracted by using sliding window and local threshold (Fig. 1B). Finally, the venous phase shifts ($\Delta\phi$) were calculated locally (Fig. 1C). Δf map (Fig. 1D) was created according to the following formulas with oxygen saturation changes (ΔY) [2,3].

$$\frac{\Delta\varphi_1 - \Delta\varphi_0}{\Delta\varphi_0} = \frac{(1-Y_1)-(1-Y_0)}{1-Y_0} = \frac{Y_0 - Y_1}{1-Y_0} = \frac{-\Delta Y}{1-Y_0} \qquad \Delta Y_{flow} = Y_1 - Y_0 = \frac{\Delta f}{1+\Delta f}(1-Y_0)$$

The SWI scans were repeatedly performed in 6 healthy volunteers to assess the stability of rest Δf. Regions of interests (ROIs) were placed in the basal ganglia and thalamus on the map. For the comparison, manual measurements of the phase change and manual calculation of Δf were done in the veins near the ROIs. SWI and pulsed ASL scans (modified flow-sensitive alternating inversion recovery technique, FAIR) were obtained in the other 4 healthy volunteers, under the 3 kinds of respiratory challenge; pure oxygen inhalation, hyperventilation, and breath-holding. The Δf measured by SWI and the CBF change (ΔCBF) measured by ASL, were compared in the ROIs of both basal ganglia and thalamus.

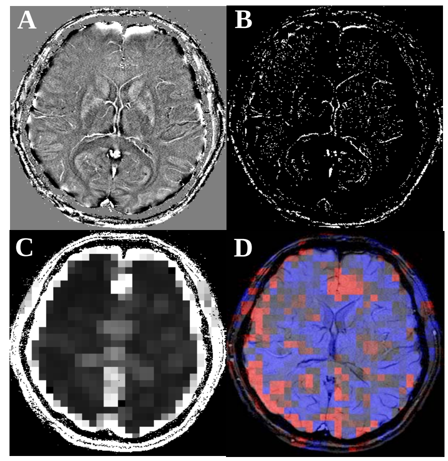

Fig. 1 (A) phase image of SWI, (B) venous image, (C) phase map, and (D) Δf map (red, high flow; blue, low flow). These maps are obtained with hyperventilation, and the decrease in blood flow is clearly seen on Δf map

Result

The mean values of rest Δf obtained by manual measurements in the veins near the basal ganglia and thalamus were 10.7% ± 39.9 and 24.7% ± 130.0, respectively. The mean values of rest Δf calculated by automated map in the ROIs were significantly smaller, 0.9% ± 3.5 and 0.7% ± 3.6, respectively.

With hyperventilation, Δf of the automated map in the ROIs decreased significantly by 8.7% ± 3.2 and 13.2% ± 9.3, respectively, compared to the resting state, and increased with breath-holding by 4.9% ± 5.1 and 7.9% ± 6.2, respectively. In contrast, Δf with inhalation of pure oxygen did not change significantly (Fig.2A). These results corresponded well to the ΔCBF observed by ASL (Fig. 2B).

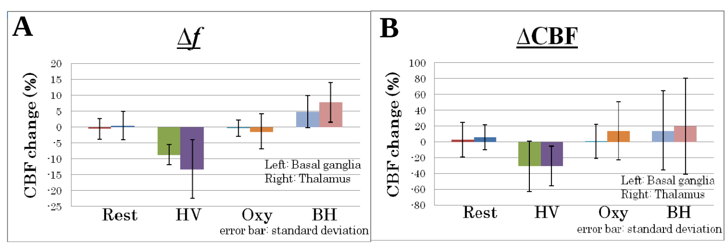

Fig. 2 (A) Δf at rest and with each respiratory stress; hyperventilation (HV), pure oxygen inhalation (Oxy), breath-holding (BH) in the basal ganglia and thalamus, (B) ΔCBF with each respiratory stress.

Conclusion

Our automated method to calculate blood flow changes by using phase images yields stable and reliable Δf value, compared to the manual measurements. Moreover, the good agreement between Δf of SWI and ΔCBF of ASL data with respiratory challenge suggests that our automated map could be an alternative and non-invasive tool for CBF measurement.

Reference

1) Haacke EM, et al. Susceptibility weighted imaging (SWI). Magn Reson Med. 2004;52:612-618.
2) Haacke EM, et al. In vivo measurement of blood oxygen saturation using magnetic resonance imaging: A direct validation of the blood oxygen level-dependent concept in functional brain imaging. Hum Brain Mapp. 1997;5:341-346.
3) Shen Y, et al. In vivo measurement of tissue damage, oxygen saturation changes and blood flow changes after experimental traumatic brain injury in rats using susceptibility weighted imaging. Magn Reson Imaging. 2007;25:219-227.